UCRL-TR-205492

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Study of Compton vs. Photoelectric Interactions

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July 26, 2004

Auspices Statement

This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

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September 3, 2003

1 Introduction

We have studied how often incoming photons interact via a Compton interaction and/or a photoelectric interaction as a function of energy and detector material Results are using a 1m^3 detector, and discrete energy photons from 0.1 MeV up to 10 MeV. Essentially all of the lower energy photons interact at least once in a detector of this size. This is not the case at higher energies. Each detector, photon energy combination was simulated with 2000 photons.

The following pages contain plots and tables showing how the following quantities vary with photon energy and detector material:

1. Fraction of photons that interact via the Compton interaction at least once.
2. Fraction of photons that do not interact via the Compton interaction, but rather are absorbed via a photoelectric interaction.
3. Fraction of photons that interact via the Compton interaction exactly once and are then absorbed via a photoelectric interaction.
4. Fraction of photons that interact via the Compton interaction at least twice.

Table 0: Summary of detector properties. The "Plastic" is polystyene scintillator. The "Glass" is a proprietary mixture used by Arno Ledebuhr from Collimated Holes, Inc. It has a LKH-6 glass core and borosilicate glass cladding.

Detector	Radiation length (cm)	Density (g/cm^3)	Effective Z
Germanium	2.30	5.32	32
Glass	4.48	3.27	≈ 31
Silicon	9.37	2.33	14
Plastic	42.55	1.03	≈ 4

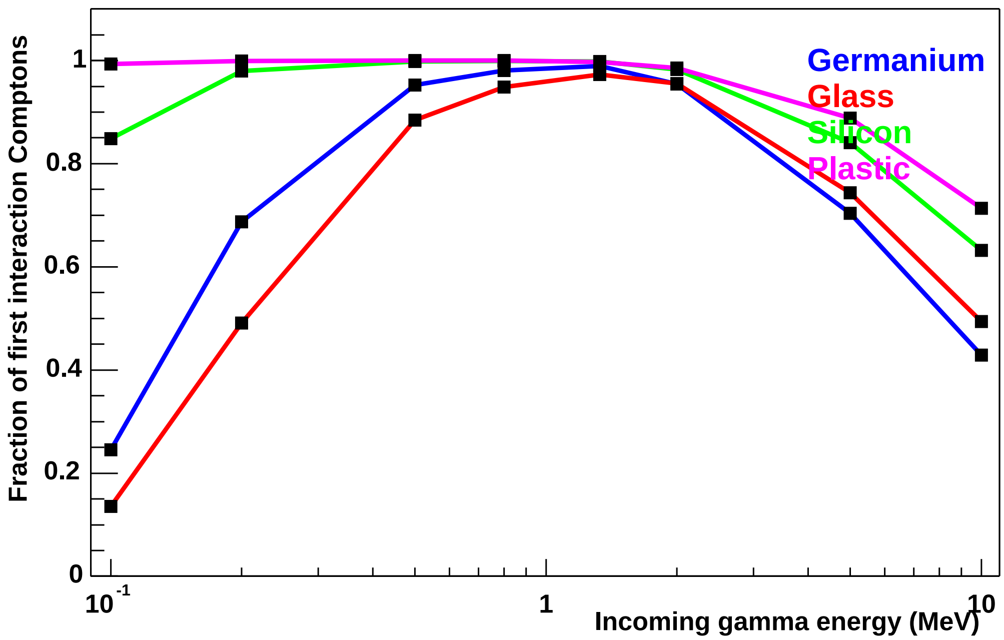

Figure 1: Fraction of gammas that undergo a Compton interaction at least once in a $1\ \mathrm{m}^3$ detector. Results are shown for the glass, plastic, silicon, and germanium based detectors.

Table 1: Percentage of gammas that undergo a Compton interaction as their first interaction in a $1\ \mathrm{m}^3$ detector.

Energy (MeV)	Germanium	Glass	Silicon	Plastic
0.1	24.55 ± 0.43	13.59 ± 0.34	84.89 ± 0.36	99.35 ± 0.08
0.2	68.74 ± 0.46	49.11 ± 0.50	97.98 ± 0.14	99.90 ± 0.03
0.5	95.27 ± 0.21	88.49 ± 0.32	99.83 ± 0.04	99.97 ± 0.02
0.8	98.04 ± 0.14	94.83 ± 0.22	99.93 ± 0.03	99.96 ± 0.02
1.33	98.96 ± 0.10	97.30 ± 0.16	99.82 ± 0.04	99.71 ± 0.05
2	95.46 ± 0.21	95.57 ± 0.21	98.22 ± 0.13	98.57 ± 0.12
5	70.37 ± 0.46	74.38 ± 0.44	84.12 ± 0.37	88.88 ± 0.31
10	42.90 ± 0.49	49.44 ± 0.50	63.17 ± 0.48	71.30 ± 0.45

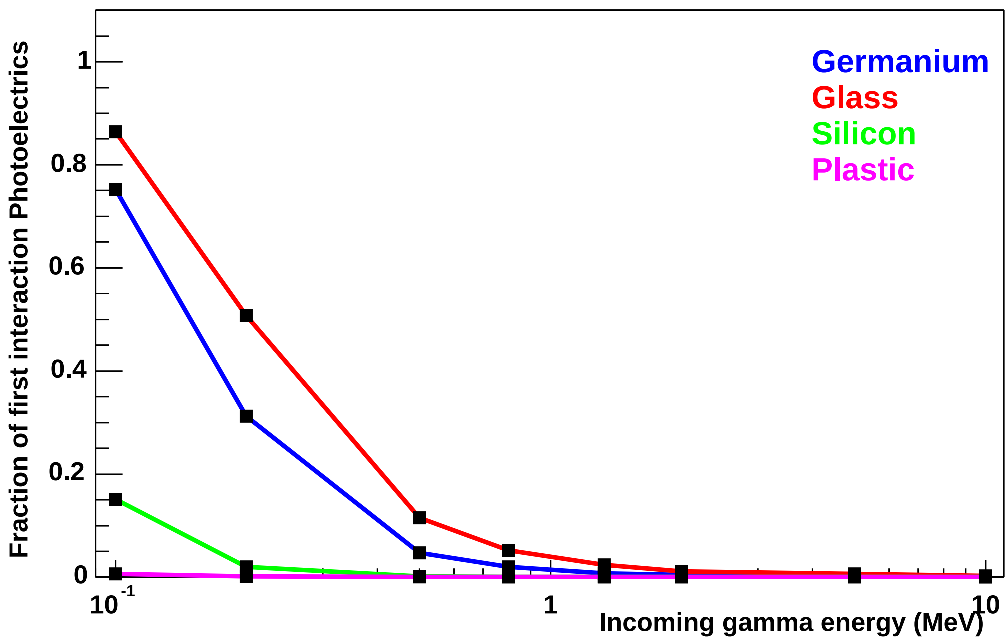

Figure 2: Fraction of gammas that undergo a photoelectric interaction as their first interaction in a $1\ \mathrm{m}^3$ detector. Results are shown for the glass, plastic, silicon, and germanium based detectors.

Table 2: Percentage of gammas that undergo a photoelectric interaction as their first interaction in a $1\ \mathrm{m}^3$ detector.

Energy (MeV)	Germanium	Glass	Silicon	Plastic
0.1	75.3 ± 0.43	86.4 ± 0.34	15.1 ± 0.36	0.7 ± 0.08
0.2	31.3 ± 0.46	50.8 ± 0.50	2.0 ± 0.14	0.1 ± 0.03
0.5	4.7 ± 0.21	11.5 ± 0.32	0.2 ± 0.04	0.0 ± 0.01
0.8	2.0 ± 0.14	5.2 ± 0.22	0.1 ± 0.03	0.0 ± 0.00
1.33	0.7 ± 0.08	2.3 ± 0.15	0.1 ± 0.02	0.0 ± 0.00
2	0.5 ± 0.07	1.1 ± 0.10	0.1 ± 0.03	0.0 ± 0.00
5	0.2 ± 0.04	0.6 ± 0.08	0.0 ± 0.01	0.0 ± 0.00
10	0.1 ± 0.03	0.3 ± 0.05	0.0 ± 0.01	0.0 ± 0.00

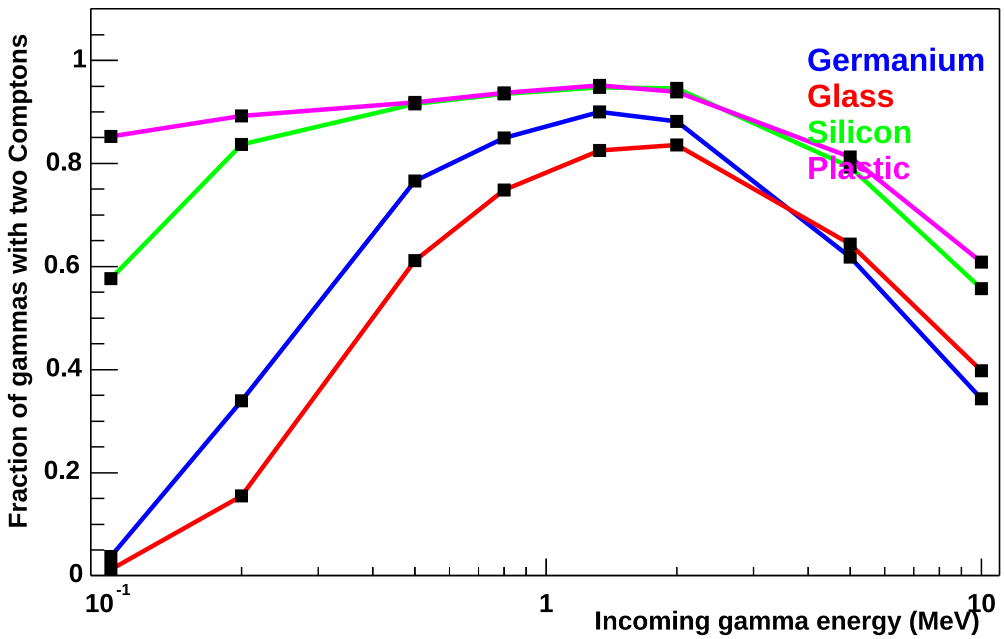

Figure 3: Fraction of gammas that undergo two Compton interactions as their first two interactions in a $1\ \mathrm{m}^3$ detector. Results are shown for the glass, plastic, silicon, and germanium based detectors.

Table 3: Percentage of gammas that undergo a two Compton interactions as their first two interactions in a $1\ \mathrm{m}^3$ detector.

Energy (MeV)	Germanium	Glass	Silicon	Plastic
0.1	3.7 ± 0.19	1.2 ± 0.11	57.6 ± 0.49	85.2 ± 0.36
0.2	33.9 ± 0.47	15.5 ± 0.36	83.7 ± 0.37	89.3 ± 0.31
0.5	76.6 ± 0.42	61.1 ± 0.49	91.5 ± 0.28	91.9 ± 0.27
0.8	84.9 ± 0.36	74.8 ± 0.43	93.5 ± 0.25	93.7 ± 0.24
1.33	90.0 ± 0.30	82.5 ± 0.38	94.8 ± 0.22	95.1 ± 0.22
2	88.1 ± 0.32	83.6 ± 0.37	94.6 ± 0.23	93.8 ± 0.24
5	61.8 ± 0.49	64.4 ± 0.48	79.3 ± 0.41	81.3 ± 0.39
10	34.3 ± 0.47	39.8 ± 0.49	55.7 ± 0.50	60.8 ± 0.49

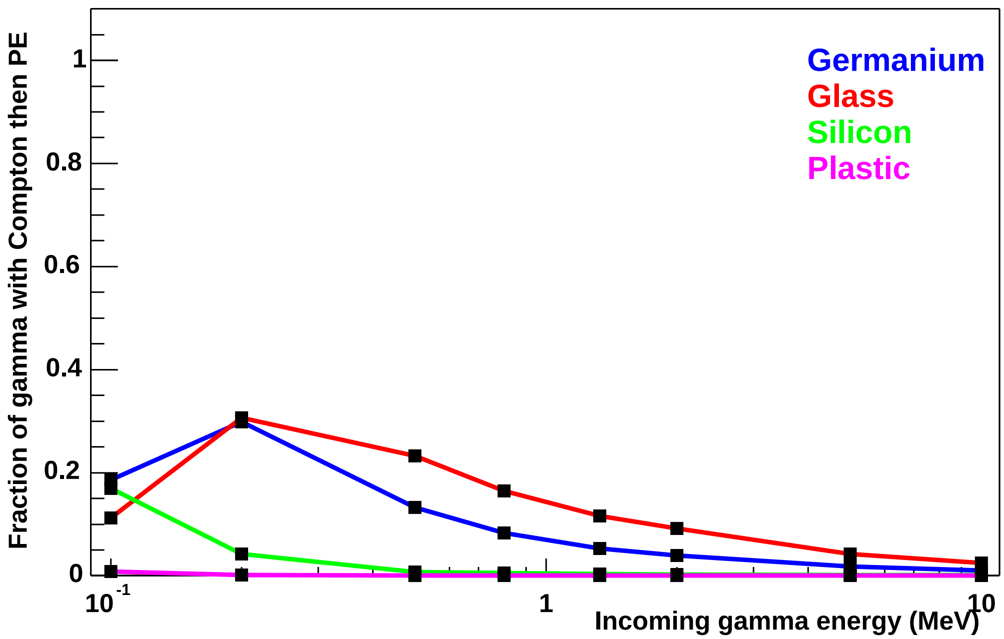

Figure 4: Fraction of gammas that undergo one Compton interaction followed by a photoelectric interaction in a $1\ \mathrm{m}^3$ detector. Results are shown for the glass, plastic, silicon, and germanium based detectors.

Table 4: Percentage of gammas that undergo a Compton interaction followed by a photoelectric interaction in a $1\ \mathrm{m}^3$ detector.

Energy (MeV)	Germanium	Glass	Silicon	Plastic
0.1	18.6 ± 0.39	11.3 ± 0.32	17.0 ± 0.38	0.8 ± 0.09
0.2	29.9 ± 0.46	30.6 ± 0.46	4.2 ± 0.20	0.2 ± 0.04
0.5	13.3 ± 0.34	23.2 ± 0.42	0.7 ± 0.09	0.0 ± 0.02
0.8	8.3 ± 0.28	16.5 ± 0.37	0.5 ± 0.07	0.0 ± 0.00
1.33	5.2 ± 0.22	11.6 ± 0.32	0.3 ± 0.06	0.0 ± 0.01
2	4.0 ± 0.20	9.2 ± 0.29	0.2 ± 0.05	0.0 ± 0.01
5	1.8 ± 0.13	4.3 ± 0.20	0.2 ± 0.04	0.0 ± 0.01
10	1.0 ± 0.10	2.5 ± 0.16	0.1 ± 0.03	0.0 ± 0.00

2 Appendix

For reference, we include the PDG plots of photon total cross sections for carbon and lead.

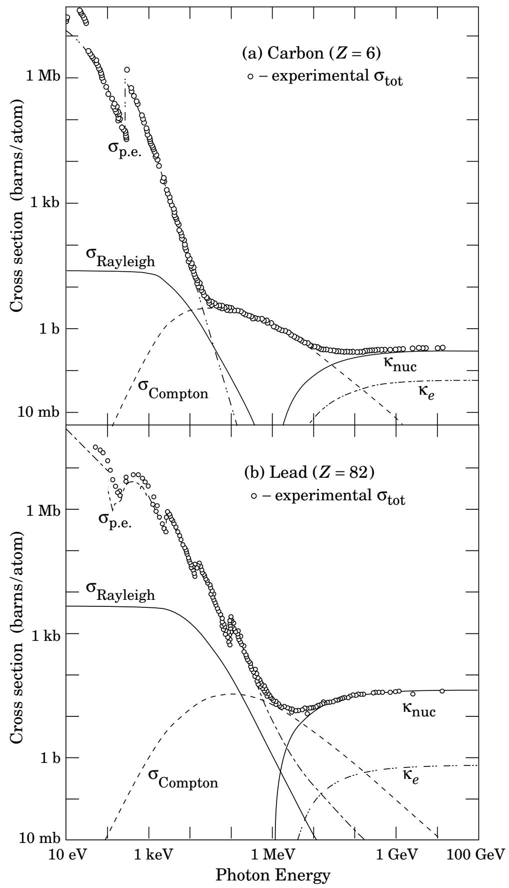

Figure 26.13: Photon total cross sections as a function of energy in carbon and lead, showing the contributions of different processes:

$\sigma_{\text{p.e.}}$ = Atomic photoelectric effect (electron ejection, photon absorption)

σ_{Rayleigh} = Coherent scattering (Rayleigh scattering—atom neither ionized nor excited)

σ_{Compton} = Incoherent scattering (Compton scattering off an electron)

κ_{nuc} = Pair production, nuclear field

κ_e = Pair production, electron field

Data from Hubbell, Gimm, and Øverbø, J. Phys. Chem. Ref. Data **9**, 1023 (1980). Curves for these and other elements, compounds, and mixtures may be obtained from
`http://physics.nist.gov/PhysRefData`. The photon total cross section is approximately flat for at least two decades beyond the energy range shown. Original figures courtesy J.H. Hubbell (NIST).